

Effects of a newly designed apparatus on orthodontic skeletal anchorage

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ABSTRACT

Objective: An appliance was designed to increase the cortical bone surface contact area of miniscrew implants (MSIs). The purpose of this *in vitro* study was to evaluate the effects of this appliance on the anchorage force resistance and the stability of orthodontic MSIs. **Materials and Methods:** A total of 48 MSIs were placed into bone specimens prepared from the ilium of bovines. Half were placed with the newly designed apparatus and half were placed conventionally. All the specimens were subjected to tangential force loading perpendicular to the MSI with lateral displacement of 0.6 mm, using an Instron Universal Testing machine. The maximum removal torque of each tested specimen was also recorded. Both study and control groups were divided into two subgroups based on whether they had thin and thick cortical bone. **Results:** The test group had statistically higher force anchorage resistance and maximum insertion torque values than the control group ($P < 0.001$). The results were found to be more significant in cases in which the cortical bone was thin ($P < 0.001$). **Conclusions:** Within the limits of this *in vitro* study, the present findings suggest that the newly designed apparatus might have a favorable effect on MSI stability in patients presenting with thin cortical bone. Clinical studies are necessary to confirm the results that were observed *in vitro*.

Key words: Anchorage, loading test, mini-implant, mini implant ring, stability

INTRODUCTION

Careful monitoring of anchorage is one of the most important factors in successful orthodontic treatment. To obtain stable anchorage, osseointegrated implants have been used to obtain absolute anchorage without the need for patient cooperation.^[1] However, osseointegrated implants require a precise 2-stage protocol and considerable time for osseointegration.^[2] In addition, these implants are expensive and there is a limited area for their insertion due to their size.

Kanomi^[3] first introduced miniscrew implants (MSIs), which can be placed almost anywhere, in either the maxilla or the mandible, with a simple procedure. Over time, the ease of placement and removal, effectiveness in anchorage without patient cooperation and benefit of their low cost has increased the popularity of these devices. Many studies and successful clinical cases have been published describing the use of MSIs for

orthodontic anchorage.^[3-5] However, MSIs can untimely be lost due to their mobility during the orthodontic treatment. The failure rate of approximately 10-40% is still unsatisfactory.^[5] Therefore, the stability of MSIs must be further improved to prevent these failure rates.

With MSIs, no waiting period is necessary for osseointegration before force application. Primary stability of an MSI is achieved immediately after insertion. The reason for this stability is believed to be a result of mechanical interlocking.^[6] Because MSIs are not osseointegrated, their anchorage potential is most likely influenced by the quantity of bone into which they are placed.^[7] In addition to bone quality and quantity, surgical technique and screw geometry are factors that affect primary stability.^[8] Because clinicians have little control over the bone quantity available for screw placement, due to the presence of roots and anatomic landmarks, screw geometry

How to cite this article: Tozlu M, Nalbantgil D, Ozdemir F. Effects of a newly designed apparatus on orthodontic skeletal anchorage. Eur J Dent 2013;7:83-8.

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DOI: 10.4103/1305-7456.119082

and surgical technique remain the parameters to be improved for the success of the procedure.

Several *in vitro* studies have been conducted to enhance the bone-screw contact area and increase the force resistance and stability (anchorage) of miniscrews by changing the length and width of the screws.^[7,9]

For the purpose of increasing the contact area at the bone-screw interface and obtaining maximum support from the cortical plate, instead of using wider screws or bicortical screws, we designed a new apparatus, a mini implant ring (MIR), placed at the neck of the screw. The purpose of this *in vitro* study was to evaluate the effects of this MIR on the anchorage force resistance (AFR) and the stability of orthodontic MSIs. The study was designed to answer the following questions. Does the MIR apparatus increase AFR? What is the effect of the MIR apparatus on the AFR and stability relative to cortical bone thicknesses (CBT)? What are the effects of the MIR apparatus on insertional torque and removal torque?

MATERIALS AND METHODS

Forty-eight self-drilling, titanium (Ti-6Al-4V) grade 5 cylindrical MSIs (TM, Trimed, Ankara, Türkiye), 1.6 mm in diameter and 9 mm in length, were used for the study [Figure 1]. The 24 MIRs used in the study group had outer diameters of 5 mm and inner diameters of 2 mm [Figure 2a-c]. They had four spines on the side, which were in contact with the cortical bone surface. The spines were 0.75 mm of length and made of titanium (Ti-6Al-4V) grade 5. A hole in the MIR was designed to fit to the neck of the MSI. A schematic and a clinical application of the MIR are shown in Figures 3 and 4.



Figure 1: The miniscrew implants used in the study

Bovine ilium was used as the bone model. The cortical thickness of the bone segments ranged from approximately 0.5 mm to 2.5 mm from the iliosacral joint toward the hip joint. These values are similar to the mean values of the cortical thicknesses of the human maxilla and mandible. The bone segments were sliced and eight bone slices, which had a minimum width of 5 mm, were obtained. Six MSIs were applied to each of the bone slices [Figure 4]. Care was taken to place the adjacent miniscrews, one from the control group and another from the study group, to ensure even distribution of the cortical thicknesses of the bone segments in both groups [Figure 5].

The MSIs were inserted with the use of a handled screwdriver (Trimed, Ankara, Türkiye) until the distance from the bone to the screw collar was 2 mm. In the MIR group, the MIR was placed with the help of a hand instrument, called an MIR pusher (Trimed, Ankara, Türkiye), for the spines to penetrate the cortical bone. In both groups, after insertion of the MSIs, final screwing, to 1 mm from final insertion depth, was performed using a torque screwdriver (N₂DPSK, Nakamura, MFG Co. Ltd.) and the maximum insertion torque (MIT) values were measured for each MSI. The remaining 1 mm distance left after final insertion was the space left for the clinical soft-tissue. In the MIR group, this distance was occupied by the height of the MIR. After insertion of all of the MSIs, the bone slices were sectioned into small blocks, which had a minimum of 4 mm of bone tissue around each screw [Figure 6].

A device was designed for positioning the bone-screw block during the embedding in acrylic resin so that the MSIs were aligned perpendicular to the axis of mechanical testing. The MSIs were subjected to a tangential force load perpendicular to the screw using an Instron test machine adjusted to a crosshead speed of 0.05 mm/s.^[7] During the loading, the displacement of the screws was measured up to a distance of 0.6 mm, which represented the adequate displacement without slippage that would result in clinical screw mobility and potential failure.^[7,9] Maximum force resistance was recorded in N/cm². Each MSI was manually examined for mobility following tangential force loading.

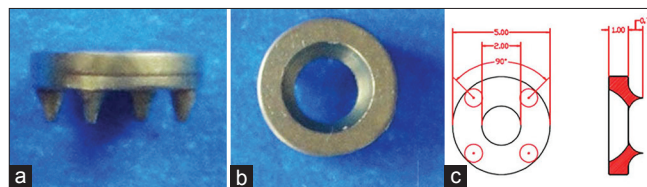


Figure 2: (a, b) Lateral and top views of the mini implant ring (MIR). (c) Dimensions of the MIR

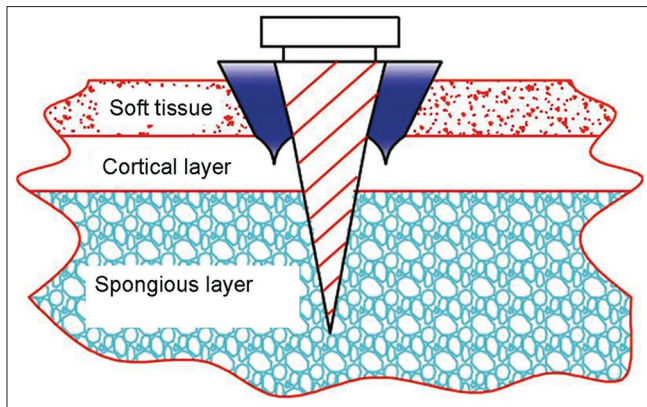


Figure 3: Diagram showing the application of the mini implant ring

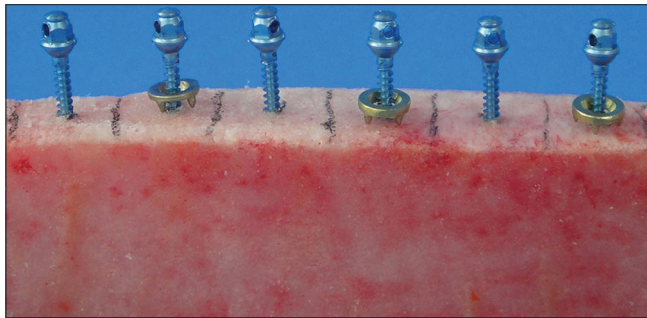


Figure 5: Miniscrew implants on bone slices and adjacent MSIs inserted, one from the control group and the other one from the test group

After the torque measurement upon removal, the samples were sectioned through the center of the miniscrew hole to examine the CBT. The mean cortical thicknesses of the bone samples for the MIR and control groups were 1.22 ± 0.49 mm and 1.23 ± 0.49 mm, respectively. Each group was divided into two subgroups and these subgroups were designated as thick or thin according to whether their CBT was greater or less than 1.15 mm [Table 1].

Statistical tests were performed with the statistical package for the social sciences (SPSS) software, (SPSS Inc., Chicago, IL, USA) version 15.0. A power analysis (G*Power version 3.1.0, Universität Kiel, Germany) revealed that a sample size of 24 for each group would provide 95% power to detect significant differences at a significance level of $P = 0.5$. The Kolmogorov-Smirnov test was performed to determine the distribution of the data. Group differences for AFR, removal torque and CBT were assessed by the independent samples *t*-test and MIT was studied with the Mann-Whitney U-test. The Chi-square test was performed to determine the differences in mobility. When $P < 0.05$, the results were considered to be significant.

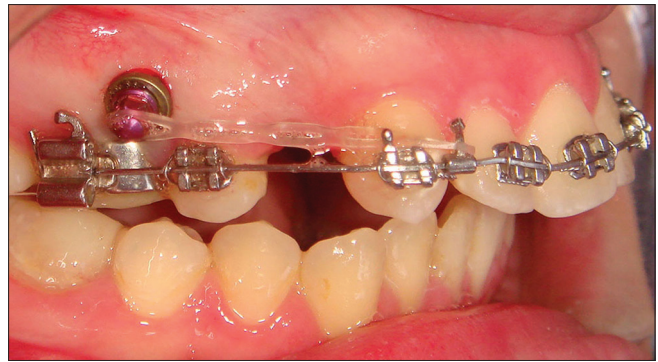


Figure 4: Miniscrew, applied with the mini implant ring that was used in a case for en masse retraction

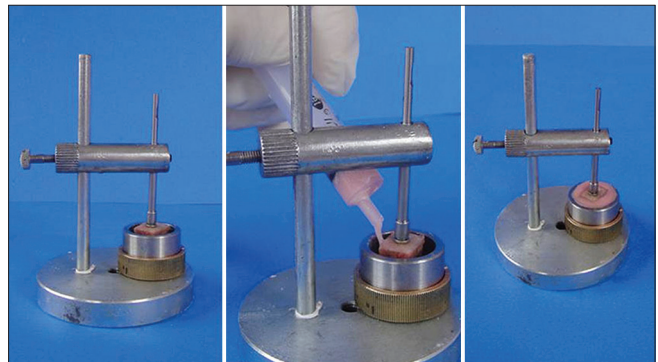


Figure 6: Embedding the bone-screw block using a custom-made positioning device

RESULTS

CBT

The mean cortical thicknesses of the bone samples for the MIR and control groups were 1.22 ± 0.49 mm and 1.23 ± 0.49 mm, respectively. Each group was divided into two subgroups and these subgroups were designated as thick or thin. The mean CBT for the thick subgroups was significantly greater than that for the thin subgroups ($P < 0.001$). The mean CBT for the thin subgroups (MIR and control) and thick subgroups (MIR and control) were similar when compared [Table 1].

AFR

MSIs inserted with MIRs showed significantly greater anchorage force values, compared with MSIs inserted without MIRs ($P < 0.001$). In the subgroups with thin cortical bone, the AFR of the MSIs inserted with MIRs was significantly greater than the AFR of MSIs inserted without MIRs ($P < 0.001$). In addition, in the subgroups with thick cortical bone, the anchorage values of MSIs inserted with MIRs were significantly greater than those inserted without MIRs ($P < 0.05$). CBT had an effect on the AFR of the MSIs in the control group [Table 2], whereas the anchorage resistance

did not differ significantly with regard to CBT if the miniscrews were applied with MIRs ($P > 0.05$).

MIT

MSIs inserted with MIRs showed significantly greater insertion torque values when compared with MSIs inserted without MIRs ($P < 0.01$). The insertion torque values of MSIs inserted with MIRs in the thin cortical bone group were significantly greater than those of the MSIs of the control group inserted to thin cortical bone ($P < 0.05$). In addition, the insertion torque into the thick cortical bone of the MIR group was significantly greater than that in the control group ($P < 0.05$). Cortical thickness had an effect on insertion torque [Table 3]. The MIT for both MIR and control groups was significantly greater than that of the subgroups presenting with thin cortical bone ($P < 0.01$).

Maximum removal torque

The data analysis showed that the MIRs did not have a significant effect on the removal torque values either when evaluated overall or when the subgroups were evaluated separately ($P > 0.05$). CBT had an effect on removal torque [Table 4]. Bone specimens with thick cortical bone had significantly greater removal torque values than specimens from the thin subgroups ($P < 0.01$).

Mobility test

There were more mobile screws in the control group than in the MIR group, but the difference was not statistically significant ($P > 0.05$). CBT had an effect on the mobility of the miniscrews in the control group ($P < 0.05$). However, the mobility of miniscrews inserted with MIRs was not significantly affected in

Table 1: Intergroup comparison of the CBT

Groups	CBT (mm) (mean±SD)	Subgroups	CBT (mm) (mean±SD)	P
MIR group	1.22±0.49	Thin	0.80±0.19	***
		Thick	1.64±0.28	
Control group	1.23±0.49	Thin	0.85±0.19	***
		Thick	1.66±0.35	
P	NS		NS	NS

CBT: Cortical bone thicknesses, MIR: Mini implant ring, SD: Standard deviation, NS: Not significant. *** $P < 0.001$

Table 2: Intergroup comparison of the AFR

Groups	AFR (N/cm ²) (mean±SD)	Subgroups	AFR (N/cm ²) (mean±SD)	P
MIR group	14.77±2.83	Thin	14.24±2.84	NS
		Thick	15.31±2.83	
Control group	10.88±2.77	Thin	9.64±2.71	**
		Thick	12.34±2.11	
P	***		***	*

MIR: Mini implant ring, AFR: Anchorage force resistance, SD: Standard deviation, NS: Not significant. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 3: Intergroup comparison of the MIT

Groups	MIT (N/cm ²) (mean±SD)	Subgroups	MIT (N/cm ²) (mean±SD)	P
MIR group	15.30±4.32	Thin	12.43±4.41	**
		Thick	18.17±1.27	
Control group	11.50±4.32	Thin	8.71±3.29	**
		Thick	14.8±2.80	
P	**		*	*

MIR: Mini implant ring, MIT: Maximum insertion torque, SD: Standard deviation, NS: Not significant. * $P < 0.05$, ** $P < 0.01$

Table 4: Intergroup comparison of the MRT

Groups	MRT (N/cm ²) (mean±SD)	Subgroups	MRT (N/cm ²) (mean±SD)	P
MIR group	8.37±4.47	Thin	5.81±3.28	**
		Thick	10.93±4.93	
Control group	7.0±4.46	Thin	4.55±3.26	**
		Thick	9.89±4.00	
P	NS		NS	NS

MRT: Maximum removal torque, MIR: Mini implant ring, SD: Standard deviation, NS: Not significant. ** $P < 0.01$

terms of CBT ($P > 0.05$). A comparison of the mobility of the MSIs is provided in Table 5.

DISCUSSION

Several reasons explain the failure of orthodontic MSIs. The stability of these small-sized appliances depends on parameters such as the properties of the hard and soft-tissues, screw design, insertion procedure and the amount of force applied.^[10,11] However, the key determinant for stationary anchorage is the quality and quantity of the bone into which the MSIs are placed.^[10,12] Motoyoshi *et al.*^[11] evaluated the effect of CBT on the success of MSIs and concluded that the insertion site should have a CBT of at least 1 mm. Miyawaki *et al.*^[10] stated that when using MSIs in patients with a high mandibular plane angle, special care should be taken in the presence of thin cortical bone to avoid failures. It has been observed that the more screw-cortical bone contact there is, the greater stability and resistance to failure there will be.^[13,14] Therefore, an appliance, the MIR, was designed, which increased the cortical bone surface area in contact with the anchorage unit. In this study, the effects of this unit were evaluated.

The MIR is a ring designed to increase the surface contact area of MSIs with cortical bone. It also has spines entering the bone to increase the resistance against floating. Nalbantgil *et al.*,^[15] using finite element analysis, concluded that the spines on the miniplates were highly efficient in reducing the stress on the fixation screws. In general, with conventional screw implants, the load concentration has a tendency to occur on the first threads, leading to increased stress on the surrounding cortical bone and possibly resulting in resorption.^[16] If the load can be delivered to a larger bone surface, then the damage, which is relative to stress over an area, might be reduced.^[17] As this study confirms, the greater area of distributed load is, the greater the MSI's stability and resistance to loading will be.

MSIs with larger diameters provide greater surface area, which increases torque and AFR as a result

of increased friction and greater support at the bone-to-screw interface.^[7,9] However, the insertion of an MSI with a diameter greater than 1.6 mm needs careful consideration for placement and inserting these MSIs safely is generally very difficult because of anatomic limitations.^[18]

As stated by Brettin *et al.*,^[9] CBT is an important factor in the anchorage potential of monocortical screws. These authors mentioned that if the range of CBT between groups is not too small, the effect of CBT on stability can be demonstrated. In our study, there was a significant difference in the thickness of the cortical bone between the groups. In addition, the anchorage potentials of the control group displayed significant differences between the subgroups with thin and thick cortical bones. However, the anchorage potentials of the subgroups with thin and thick cortical bones did not show any significant difference in the MIR group. For the MIR group, our hypothesis is that the MIRs were so effective that the thickness of the cortical bone did not vary sufficiently to demonstrate an effect.

As expected, a significant difference in insertion torque was found between the control and the MIR group. An increase in the insertion torque was expected due to the penetration of the spines into the cortical bone. To prevent an undesirable increase in insertion torque, a hand instrument, which we called the "MIR pusher," was designed and used to push the MIRs into cortical bone. The mean insertion torque for the MIR group was 15.30 N/cm². This force was within the limits recommended by previous studies concerning success rates^[19] and was less than the limit necessary to avoid complications, such as the breakage of the MSI.^[11]

The main purpose of this study was to determine how much the MIR would increase the force anchorage values of MSIs. We also wanted to determine the effects of MIR appliances on MIT and MRT because each of these measurements is a determinant of primary stability. Insertion torque analysis was used to measure the mechanical retention achieved by screwing^[11,14] and removal torque analysis is a method used to assess the stability and the osseointegration

Table 5: Intergroup comparison of the mobility of MSIs

Groups	No. of MSIs with mobility	Subgroups	No. of MSIs with mobility	P
MIR group	3	Thin	3	NS
		Thick	0	
Control group	8	Thin	7	*
		Thick	1	
P	NS		NS	NS

MIR: Mini implant ring, MSIs: Miniscrew implants, NS: Not significant. * $P < 0.05$

capacity of MSIs.^[20,21] We did not want to experience any unwanted increases or decreases in terms of MIT, MRT or mobility. We found a significant ($P < 0.01$) difference in terms of MIT between the control and MIR groups (this difference was within the desired limits) and we observed an improvement in terms of MRT and mobility, but the difference was not statistically significant. Within the limits of this *in vitro* study, these findings suggest that the MIR appliance increased the force anchorage resistance of MSIs without causing any biomechanical side-effects.

In this *in vitro* study, biologic changes in bone tissue could not be analyzed. However, *in vivo* reactions to immediate loading of MSIs can be replicated with *in vitro* studies because MSI stability is believed to result from mechanical interlocking and it does not require a period for osseointegration. The bone samples used in this study, which were obtained from the ilium of bovines, enabled us to standardize the testing conditions.

In the clinic, the disadvantage of using MIRs is that a punch must be used. However, no flaps, incisions or sutures are necessary. Further studies are needed to evaluate the biologic responses of soft- and hard-tissues as well as the success rate of screw anchorage, when MIRs is used.

CONCLUSIONS

Within the limits of this *in vitro* study, the results of this investigation demonstrated that the newly designed appliance (MIR) increased anchorage resistance and insertion torque, thereby increasing the primary stability and anchorage resistance of MSIs. Removal torque and mobility were not significantly affected by the MIR. The effect of the appliance was more prominent in samples with thin cortical bone. The MIR might have a favorable effect on MSI stability in patients presenting with thin cortical bone. Clinical studies are necessary to confirm the results, which were observed *in vitro*.

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Conflict of Interest: None declared